I2nd International Forum on recent Developments of CCS Implementation

16th-17th December 2015, Athens Greece

Techno-Economic Evaluation on the Effects of Impurities for Conditioning and Transport of CO_2 by Pipeline

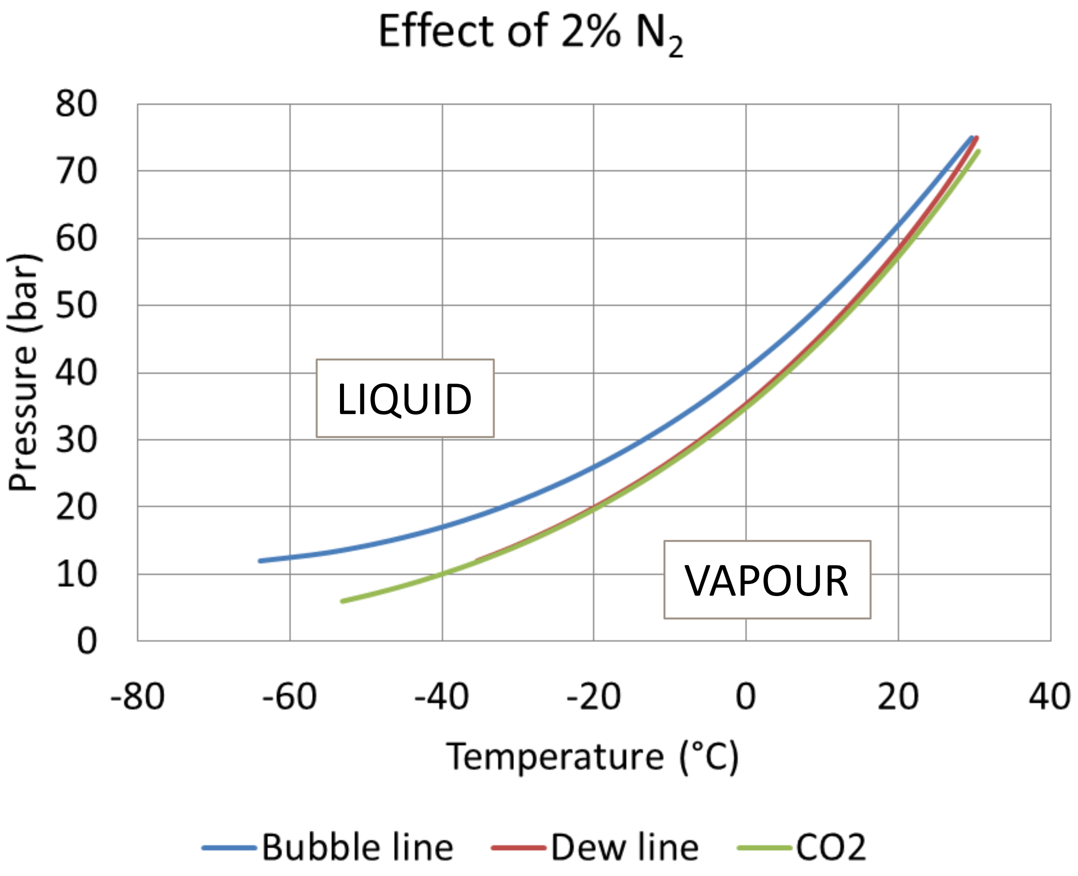
Geir Skaugen, SINTEF ER

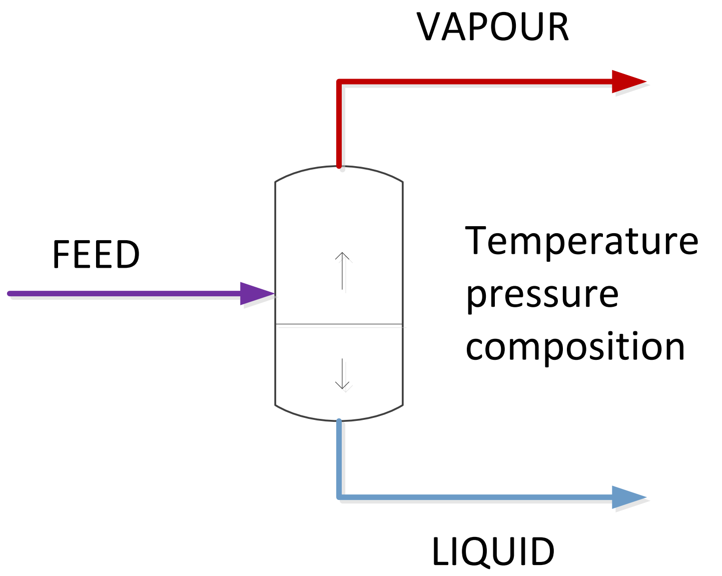
Simon Roussanaly, SINTEF ER

Introduction – Content of presentation

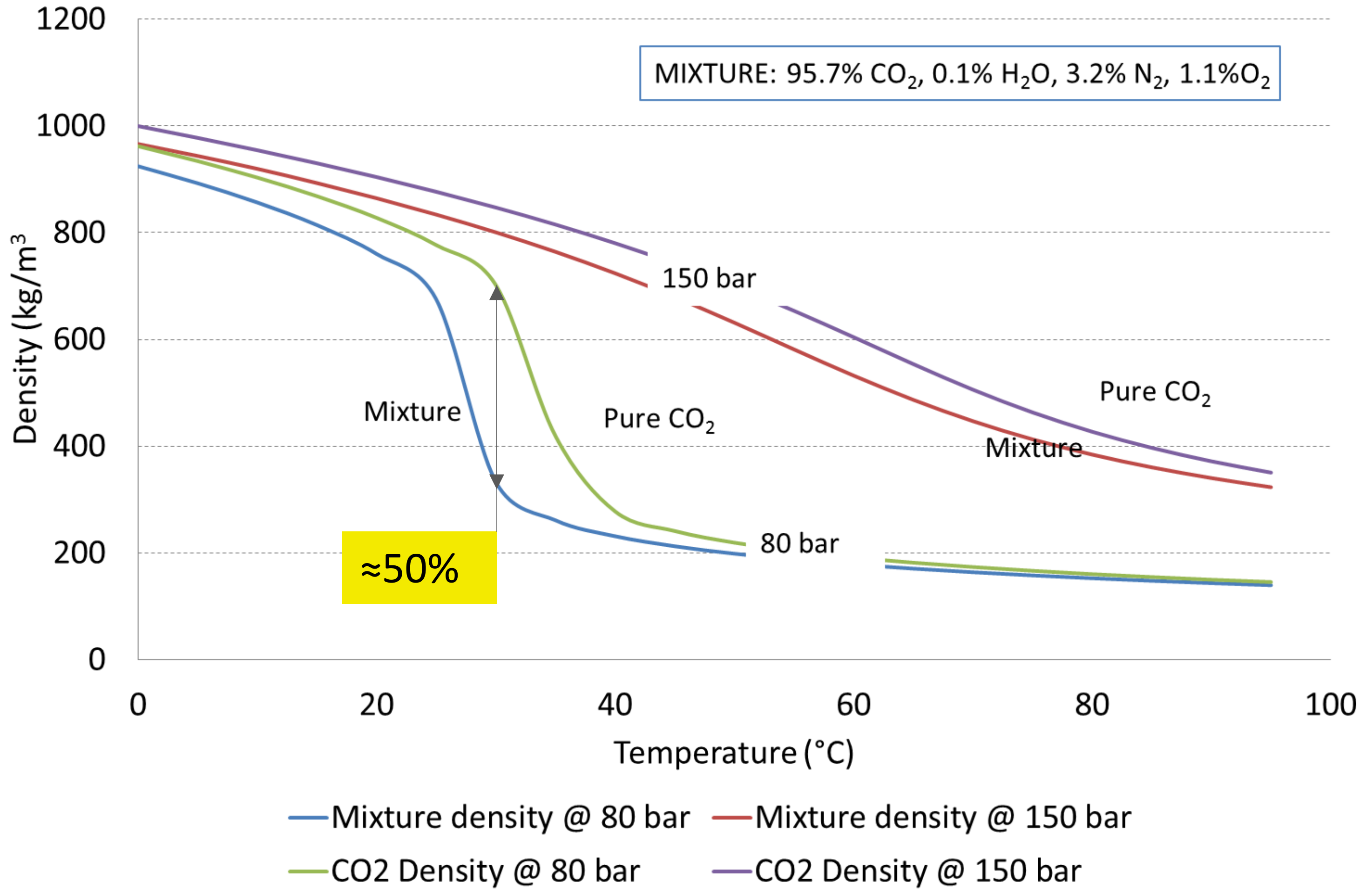
- The effect of impurities on the thermodynamic properties of CO_2 relevant for case studies
- Description case study –compressed gas for pipeline transport
- Effect of impurities on;
  - Pipeline design
  - Energy consumption
  - Cost
- Conclusion

Effects of impurities on CO_2 thermodynamic

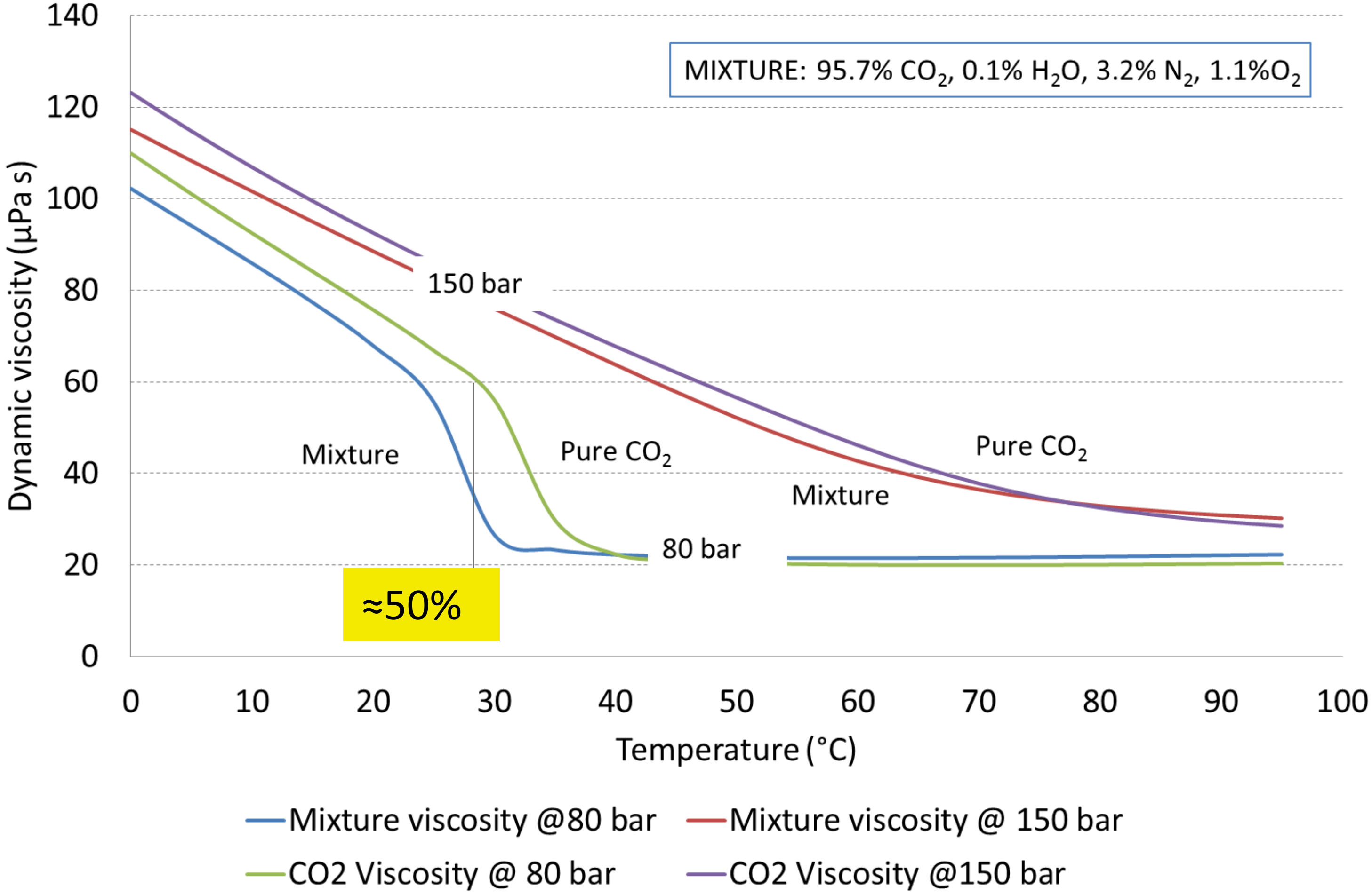




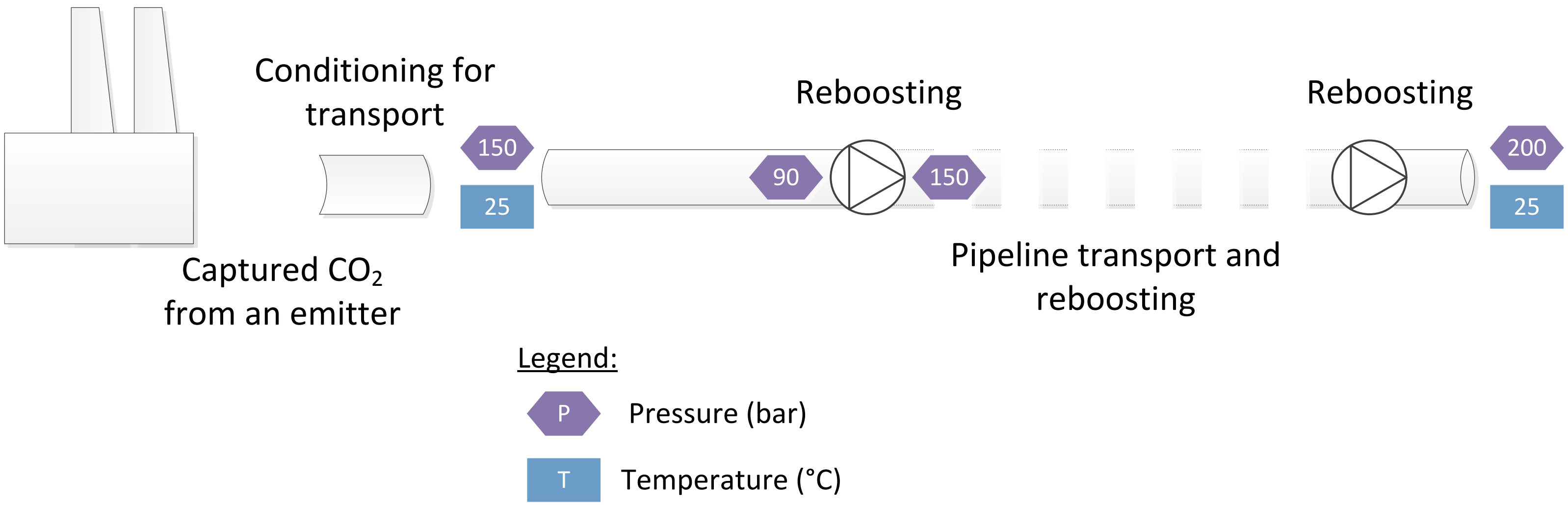
Effects of impurities on density (predictions)



Effects of impurities on viscosity (predictions)



Pipeline transport of CO_2



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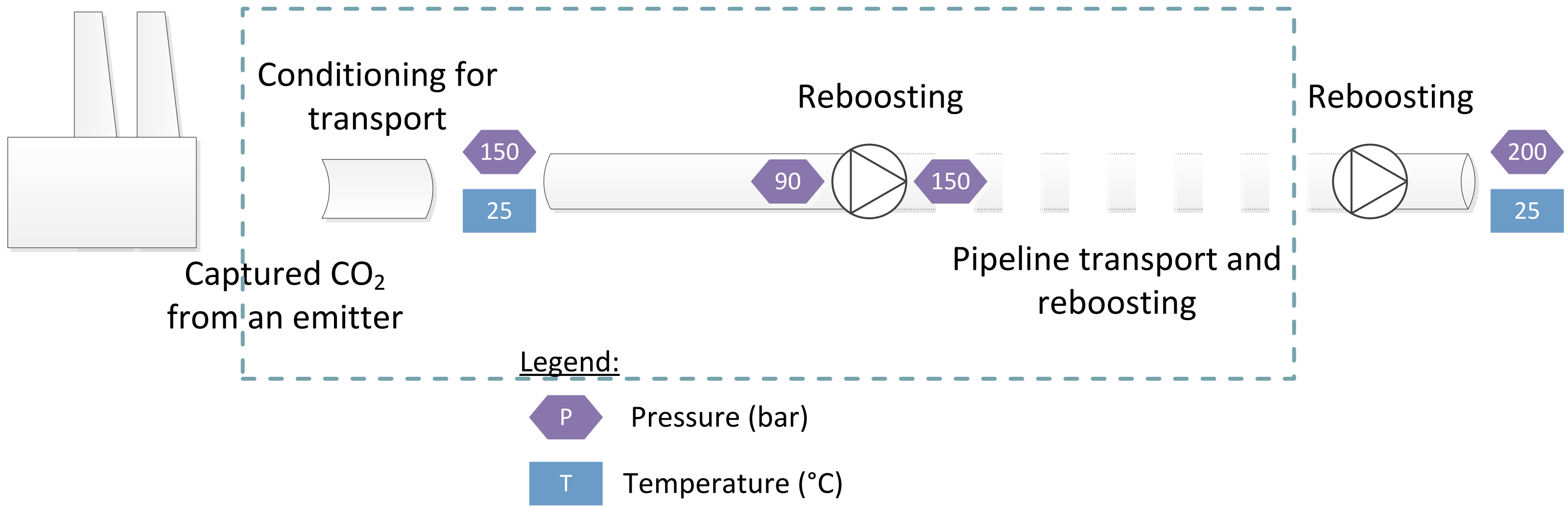


Cases, impurity levels and boundary conditions

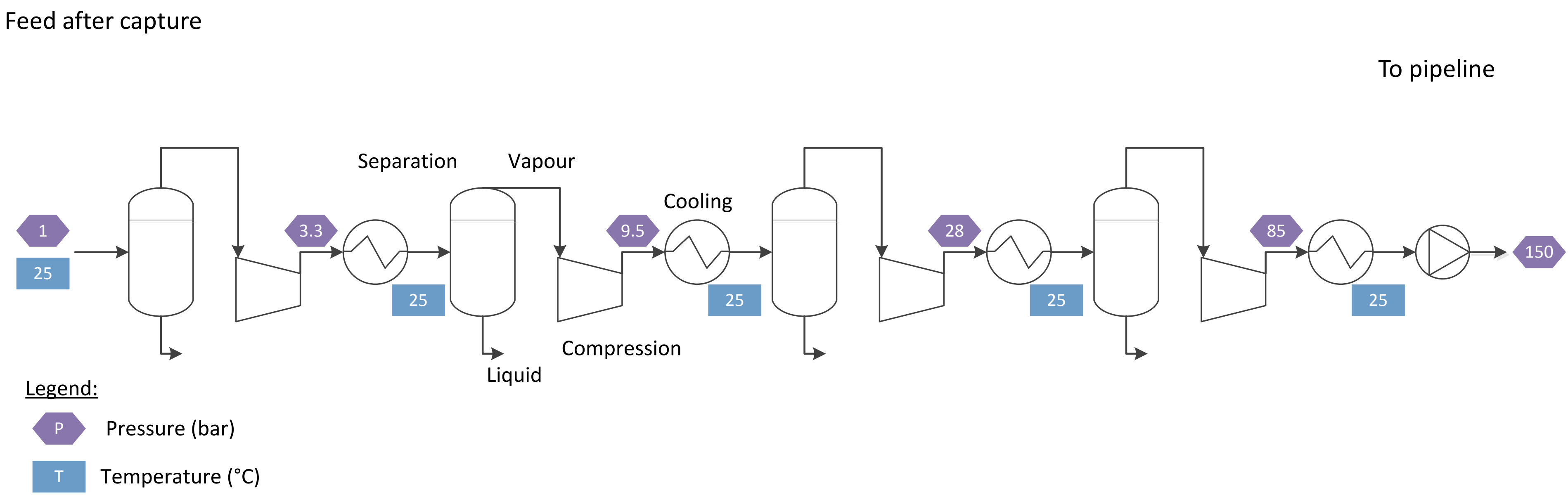
Maximum impurity levels

CASE	CO_2	H_2O	N_2	O_2	Methane
«BASE»	93	7			
«OXY»	88	7	3	2	
«GAS»	83	7	1		9

Initial condition: Atmospheric (1.027 bar and 25°C)
Export condition: 150 bar (35-38 °C)
Ambient temperature 15°C with low heat transfer:
- Ground thermal conductivity: 2.4 W/m K
- Ambient heat transfer: 5.0 W/m²K

Total transport distance: 500 km
Pipeline: On-shore @ depth 1.0 m, varying diameter
Feed flow rate: 500 kg/s (13.1 MTPA)

Pipeline transport – conditioning



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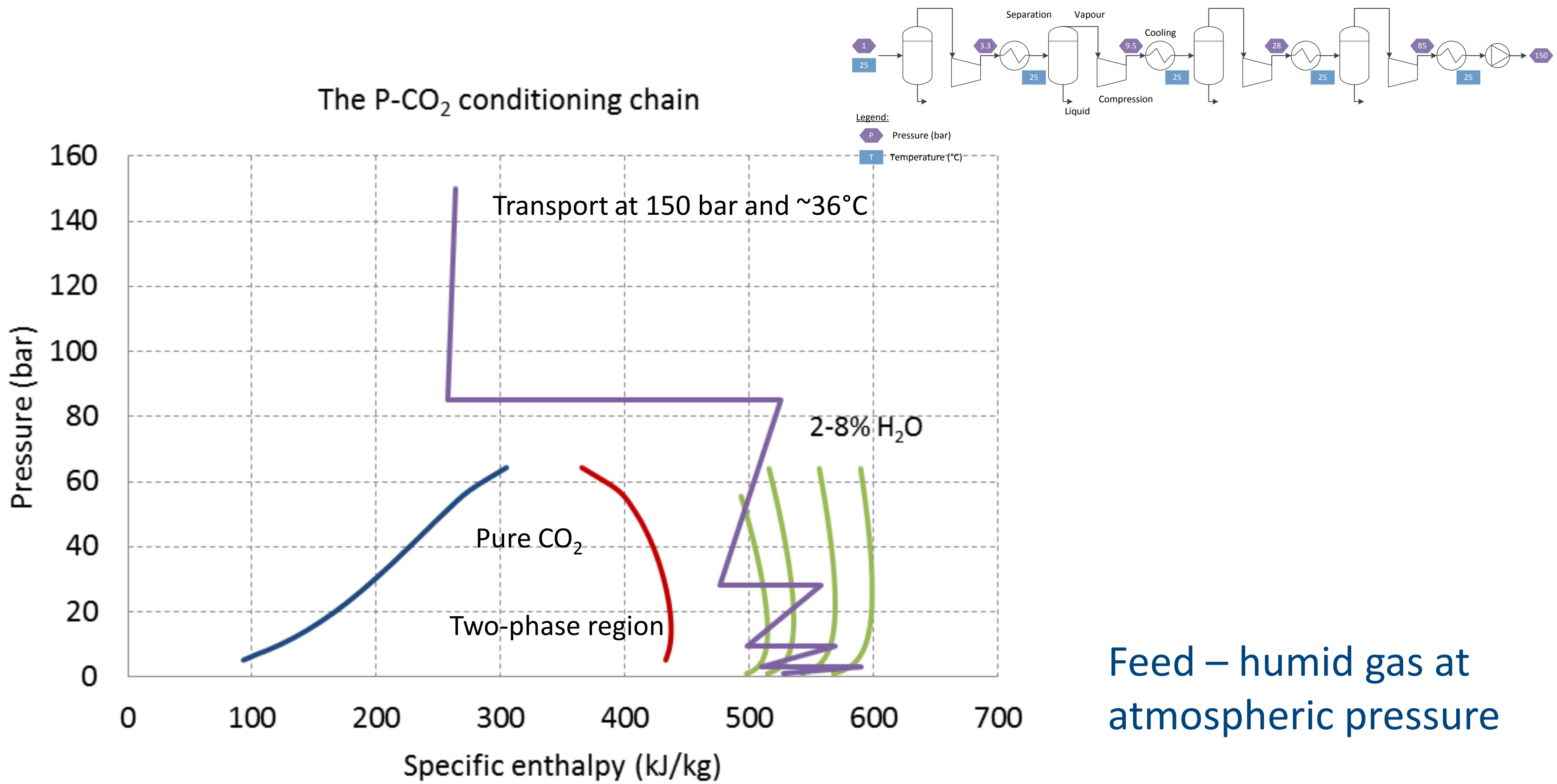
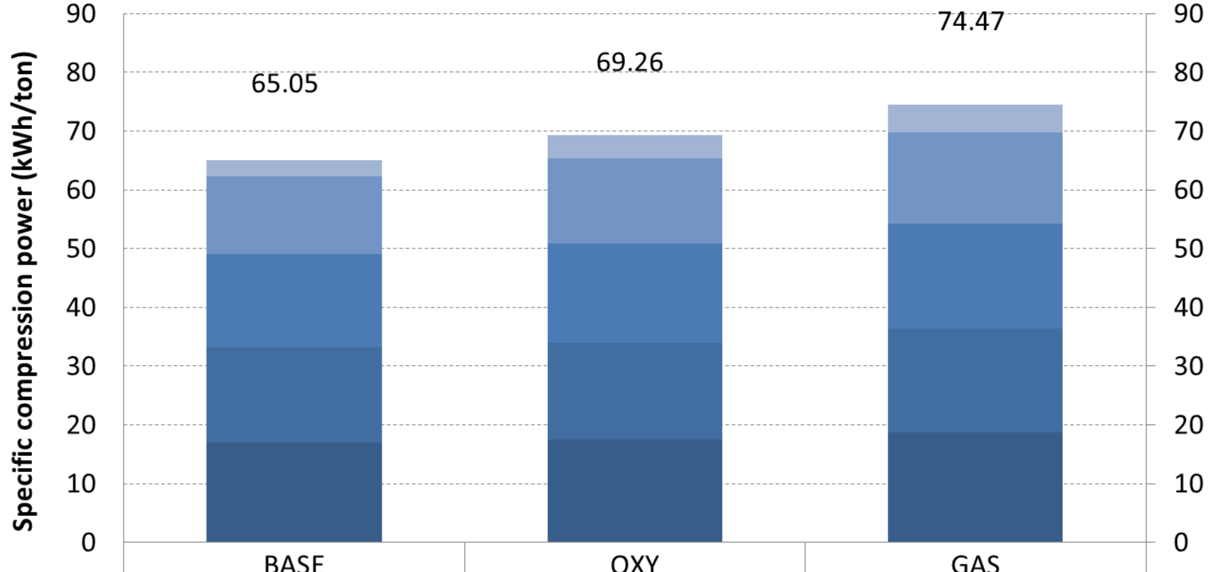


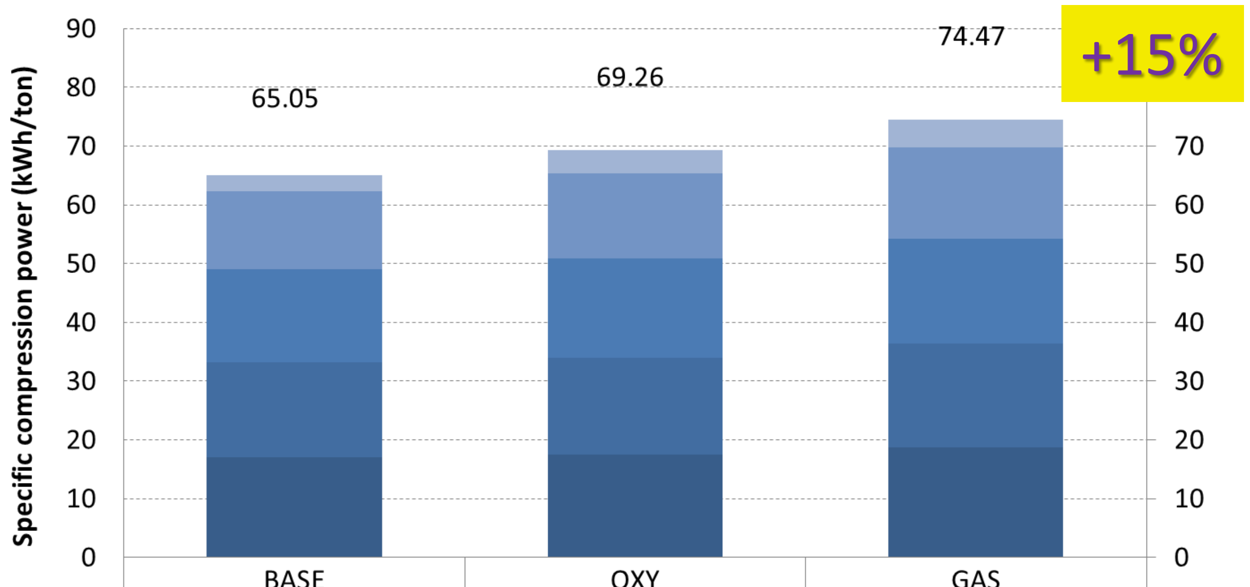
Feed – humid gas at atmospheric pressure

Power consumption for conditioning before export



	BASE	OXY	GAS
Export pump	2.80	3.91	4.76
Stage 4	13.22	14.54	15.47
Stage 3	15.90	16.82	17.81
Stage 2	16.12	16.57	17.77
Stage 1	17.00	17.43	18.66
Total	65.05	69.26	74.47

Power comsumption for conditioning for export



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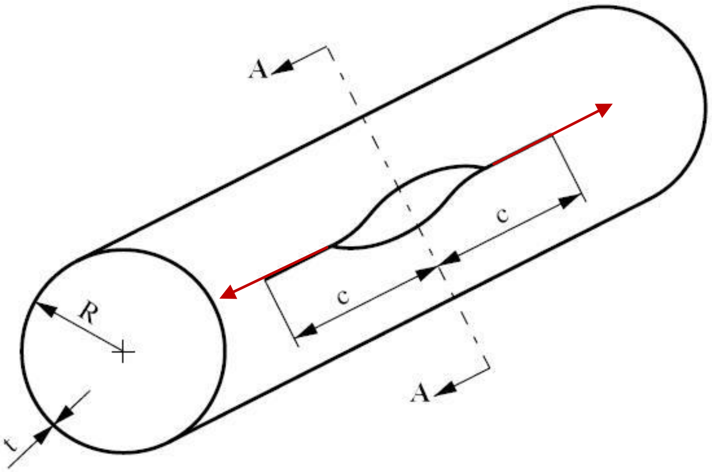
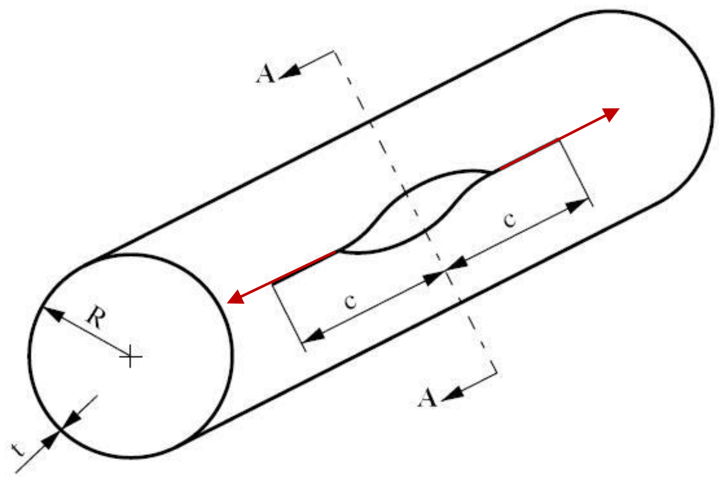
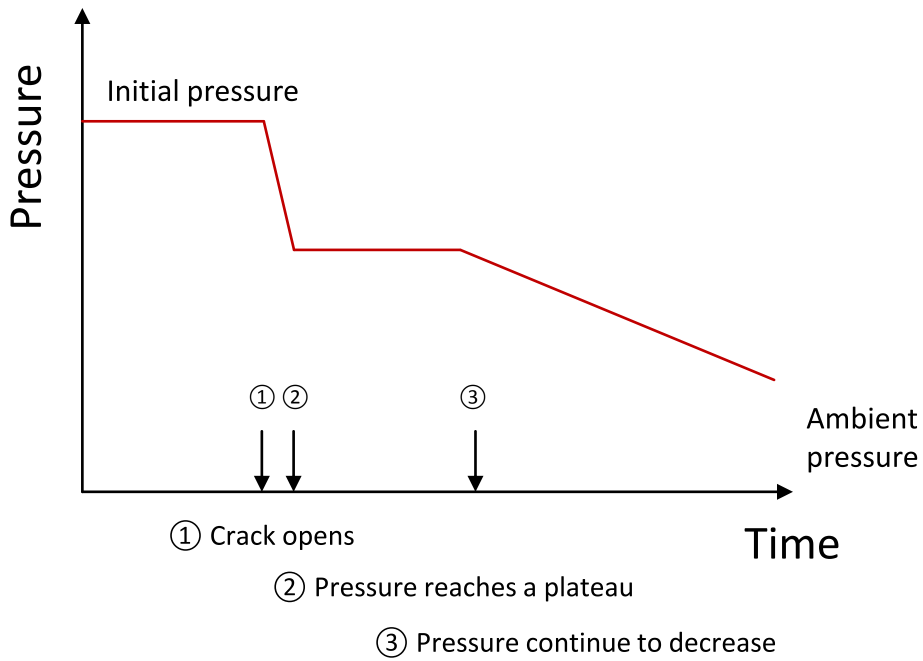
Effects from inpurity on pipe design



Question: "Will a crack in the pipeline, when initiated, propagate or will it stop?
Known as "Running Ductile Fractures" – or RDF and "crack arrest"

Fracture propagation and pipe design





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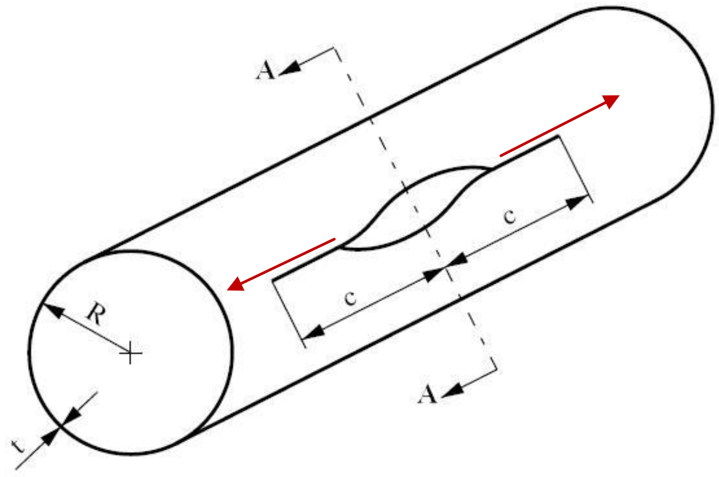

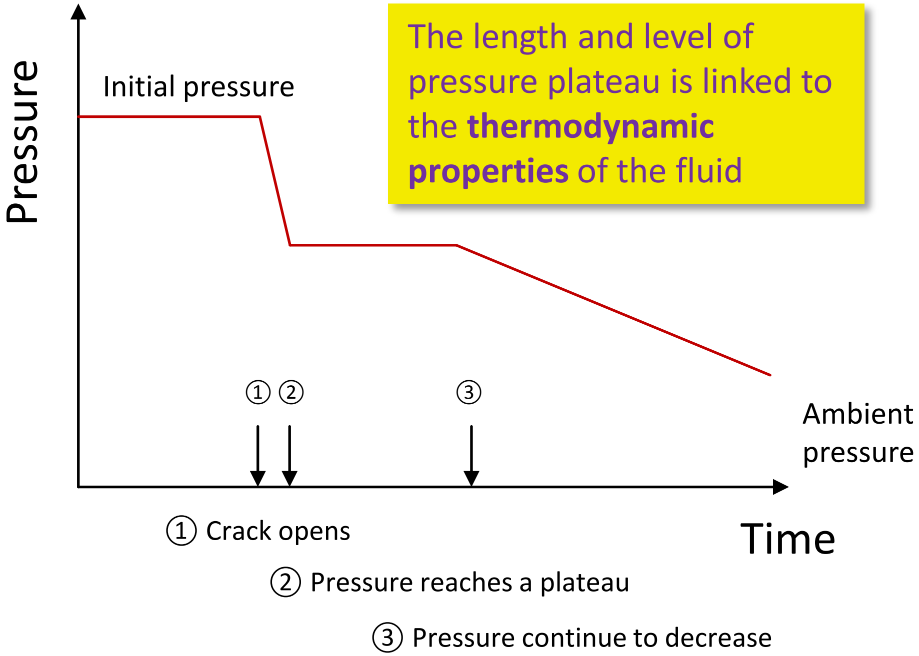

The length and level of pressure plateau is linked to the **thermodynamic properties** of the fluid

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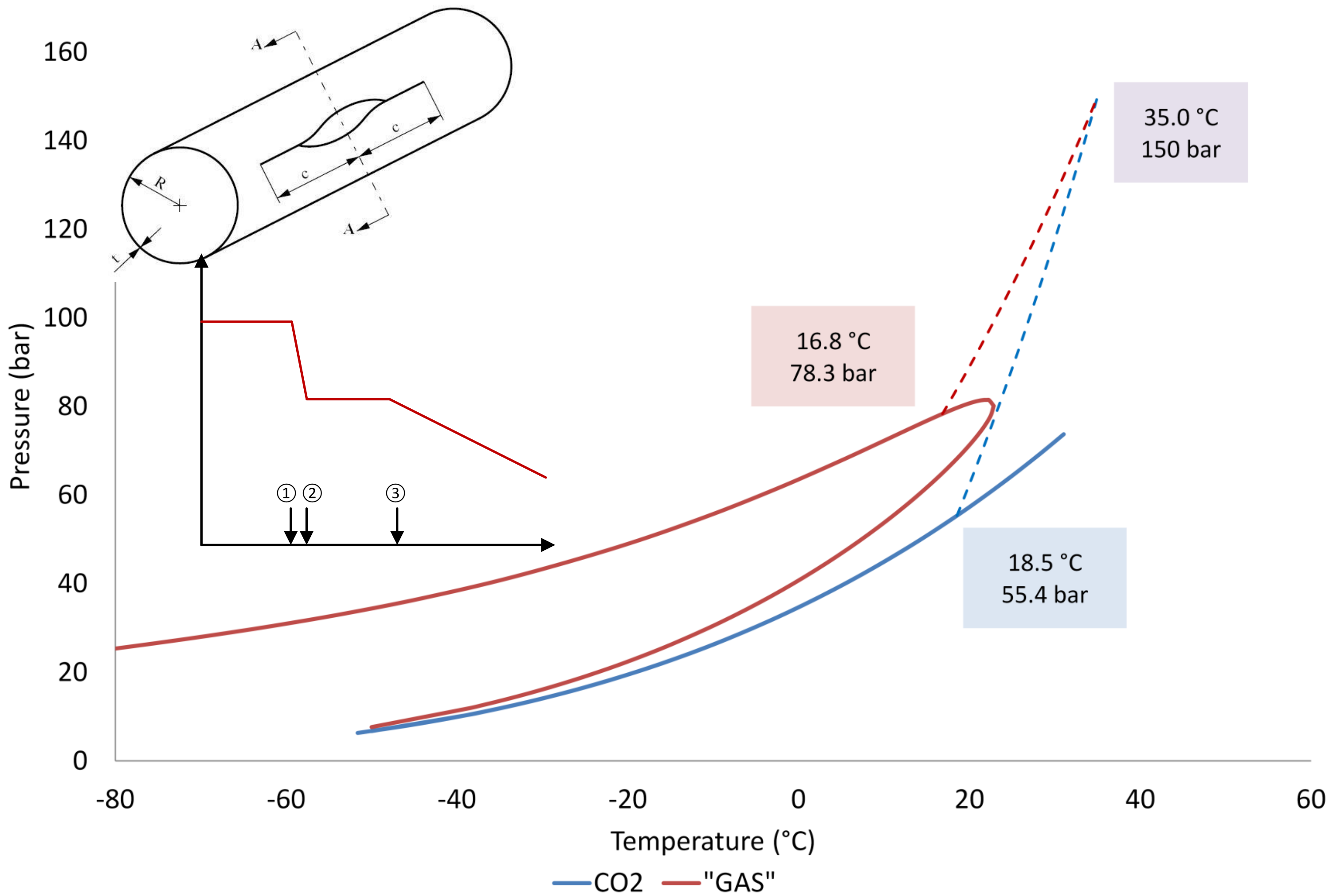
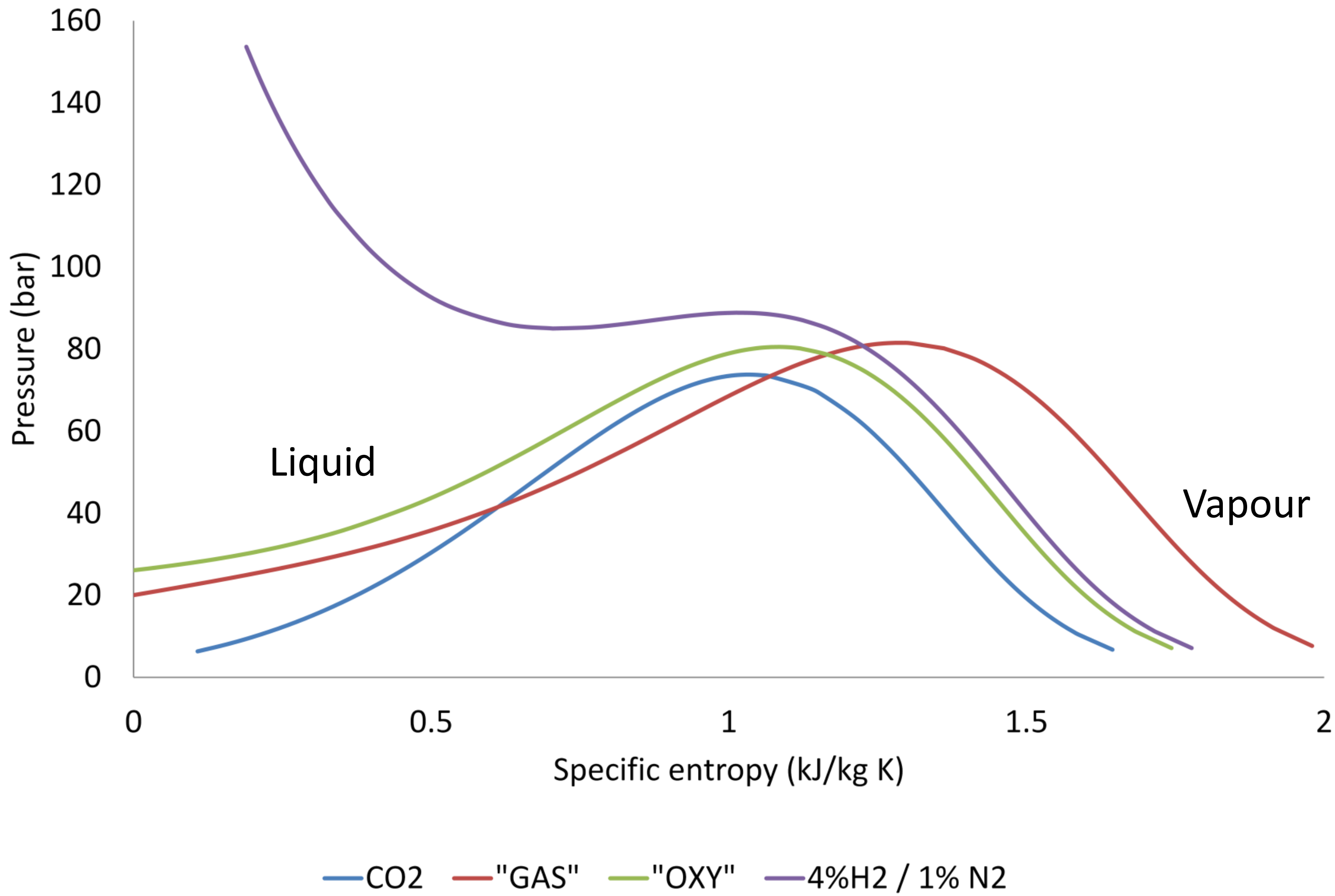
CO_2 phase behaviour – rapid pressure release – isentropic



CO_2 phase behaviour with precence of impurities



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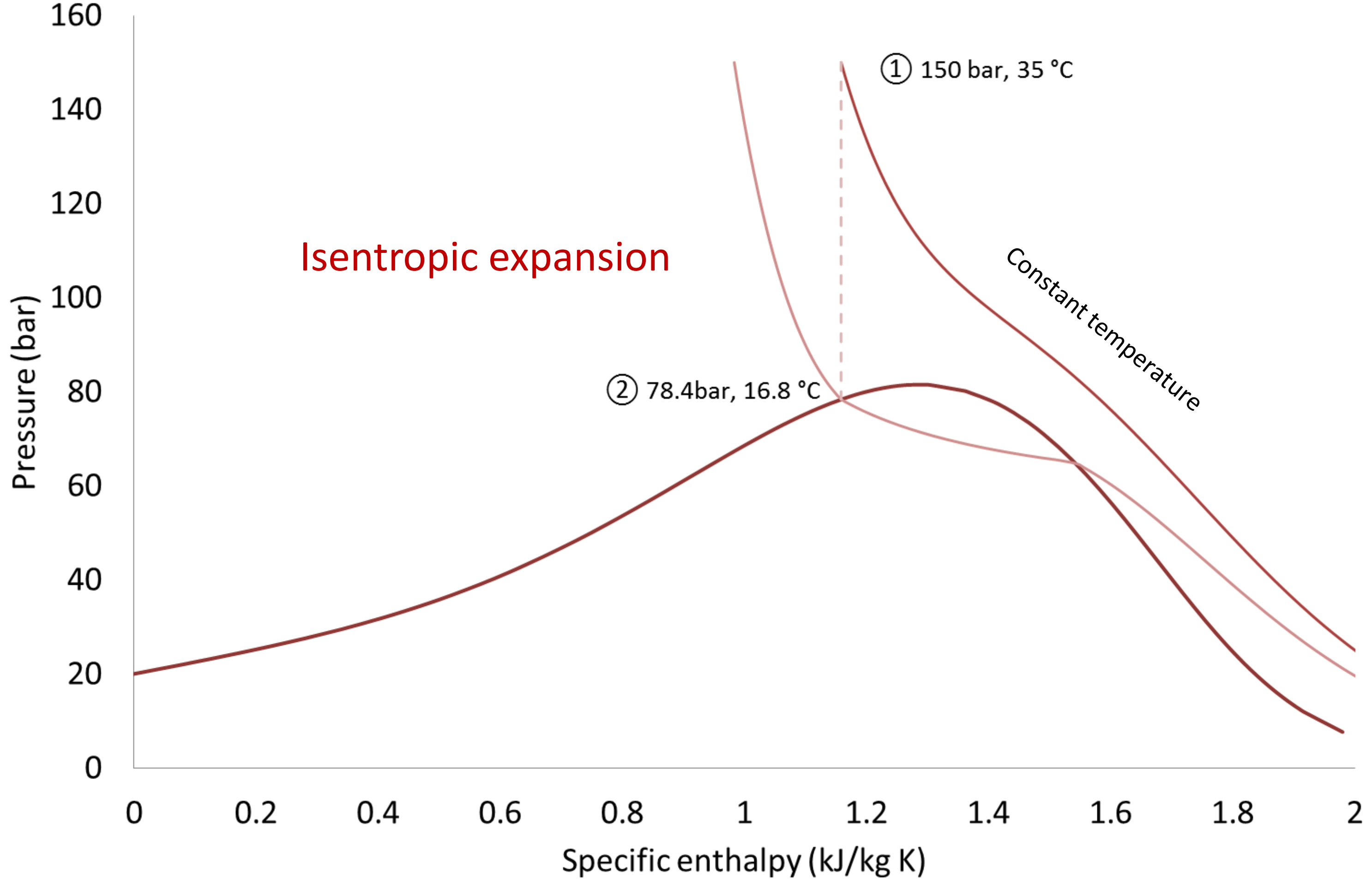
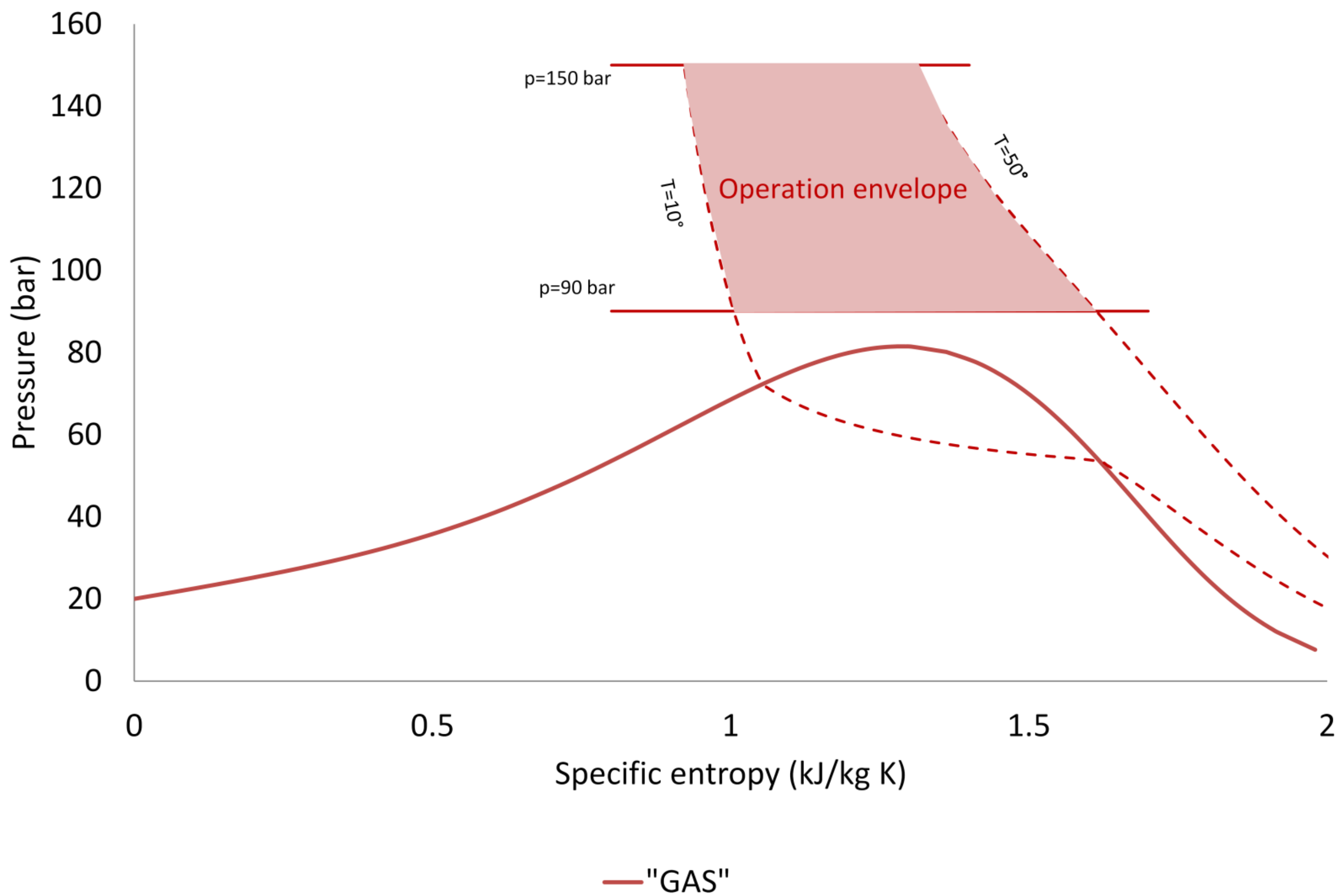


CO_2 pipeline operational envelope (Pressure – Entropy)



SMYS and RDF – how does impurities come into the eq.

SMYS – «Specified Maximum Yield Strength»

Wall thickness, *t*, determined from design pressure, P_D , yield strength, σ_o and safety factor, *f*

$$t = \frac{P_D \cdot R_0}{\sigma_0} \cdot \frac{1}{f}$$

RDF – «Running Ductile Pressure»

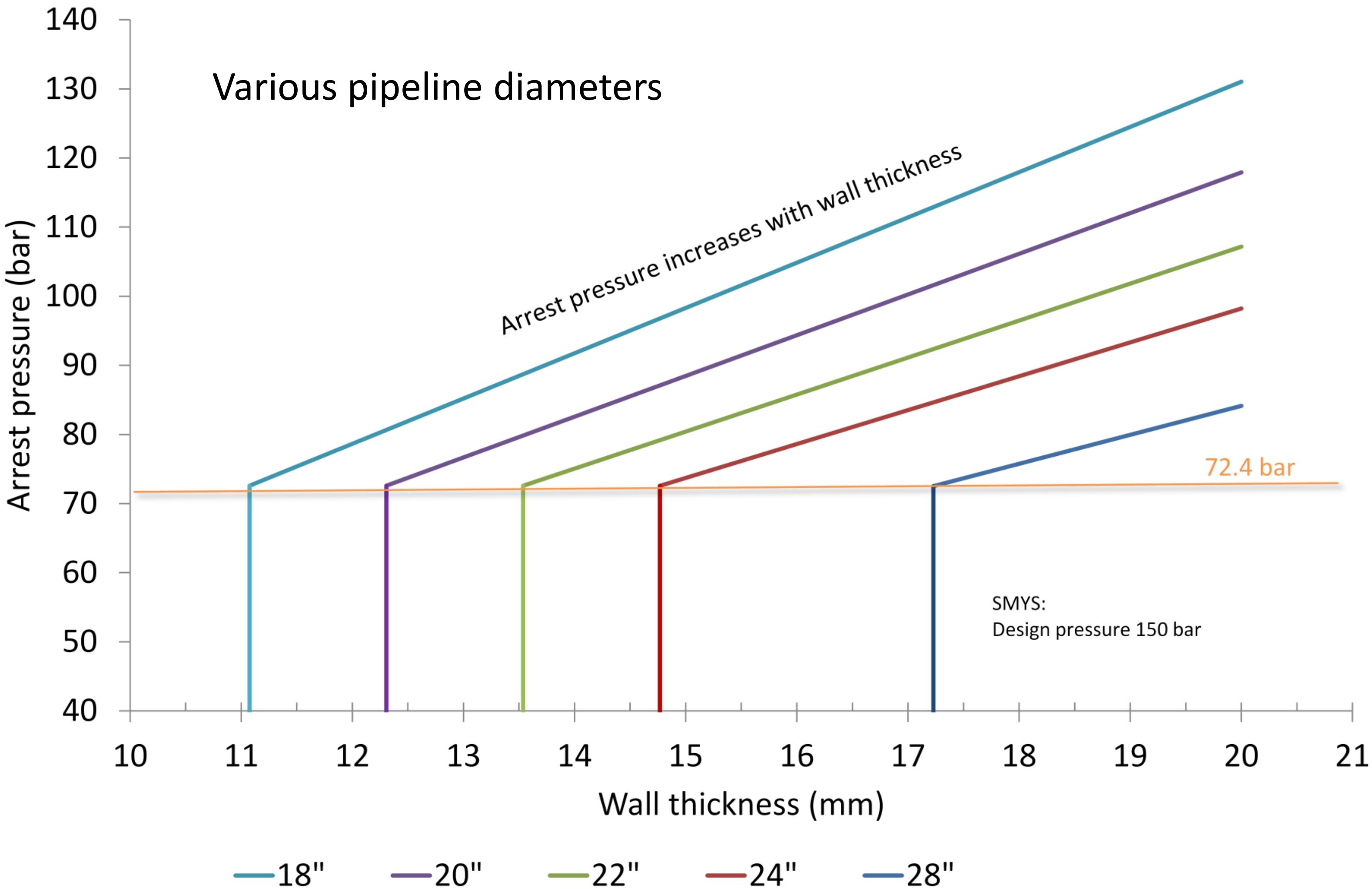
Link between the «saturation pressure» and «arrest pressure»

Very simplified: $p_{sat} < p_{arrest}$ then RDF will not occur and a crack will not propagate

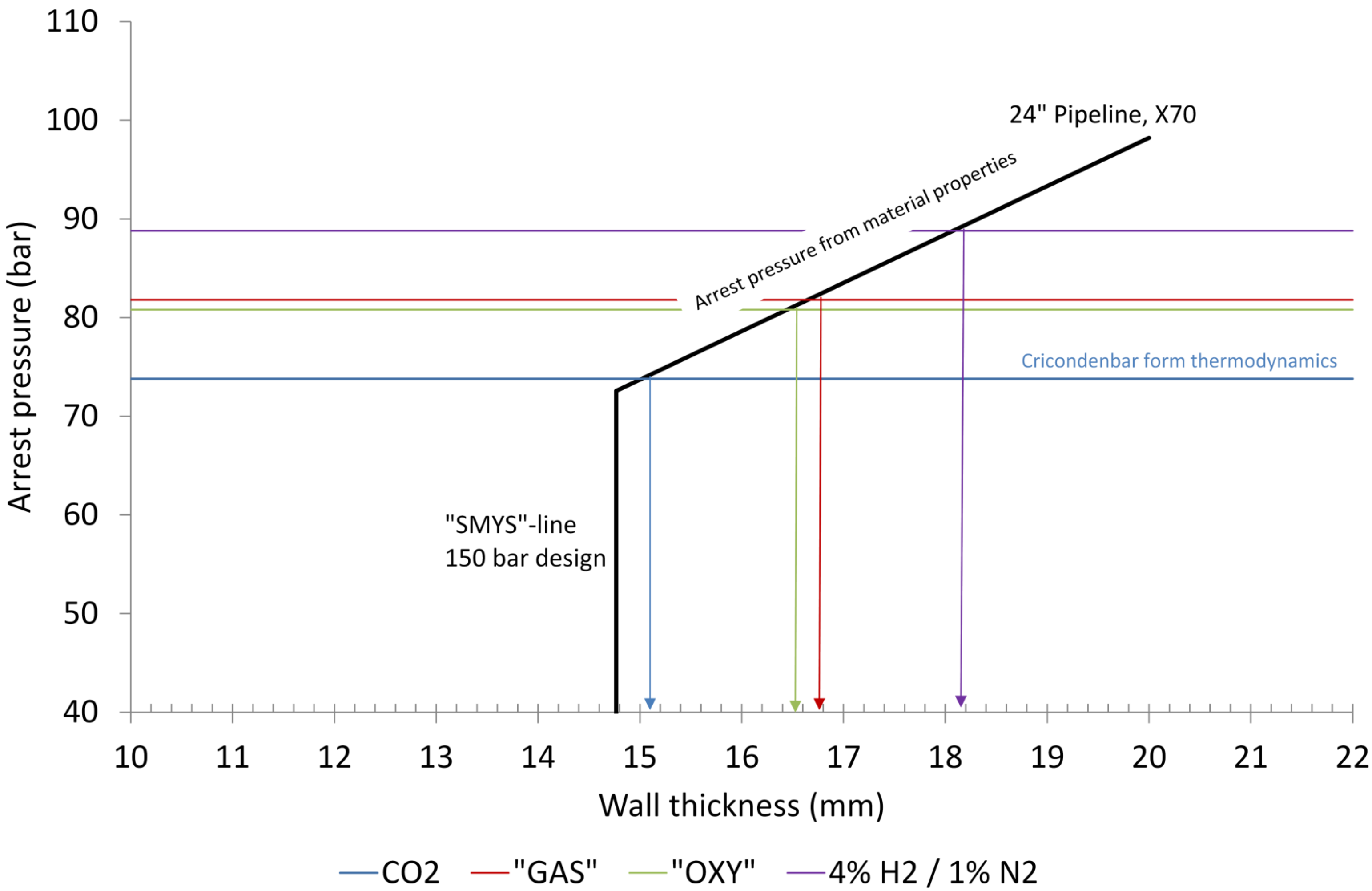
$$p_a = \frac{2 \cdot t \cdot \tilde{\sigma}}{3.33\pi R_o} \cdot \cos^{-1}\left[e^{\left(\frac{\pi R_f E}{24\tilde{\sigma}^2\sqrt{R_o \cdot t}}\right)}\right]$$

From the "Batalle Two-Curve Model"

SMYS and RDF – Effect of impurities on wall thickness



SMYS and RDF – Effect of impurities in a 24" pipeline



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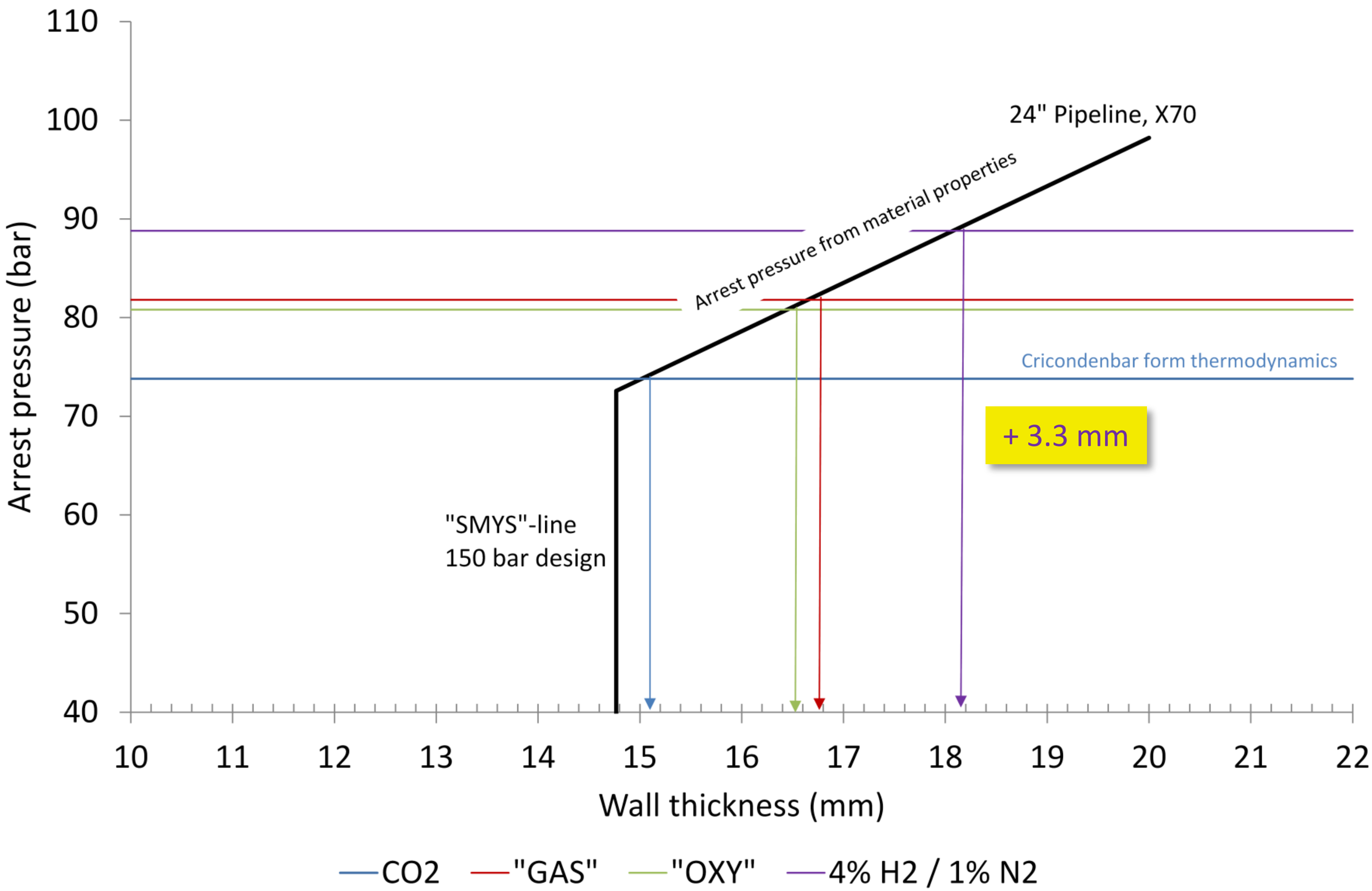

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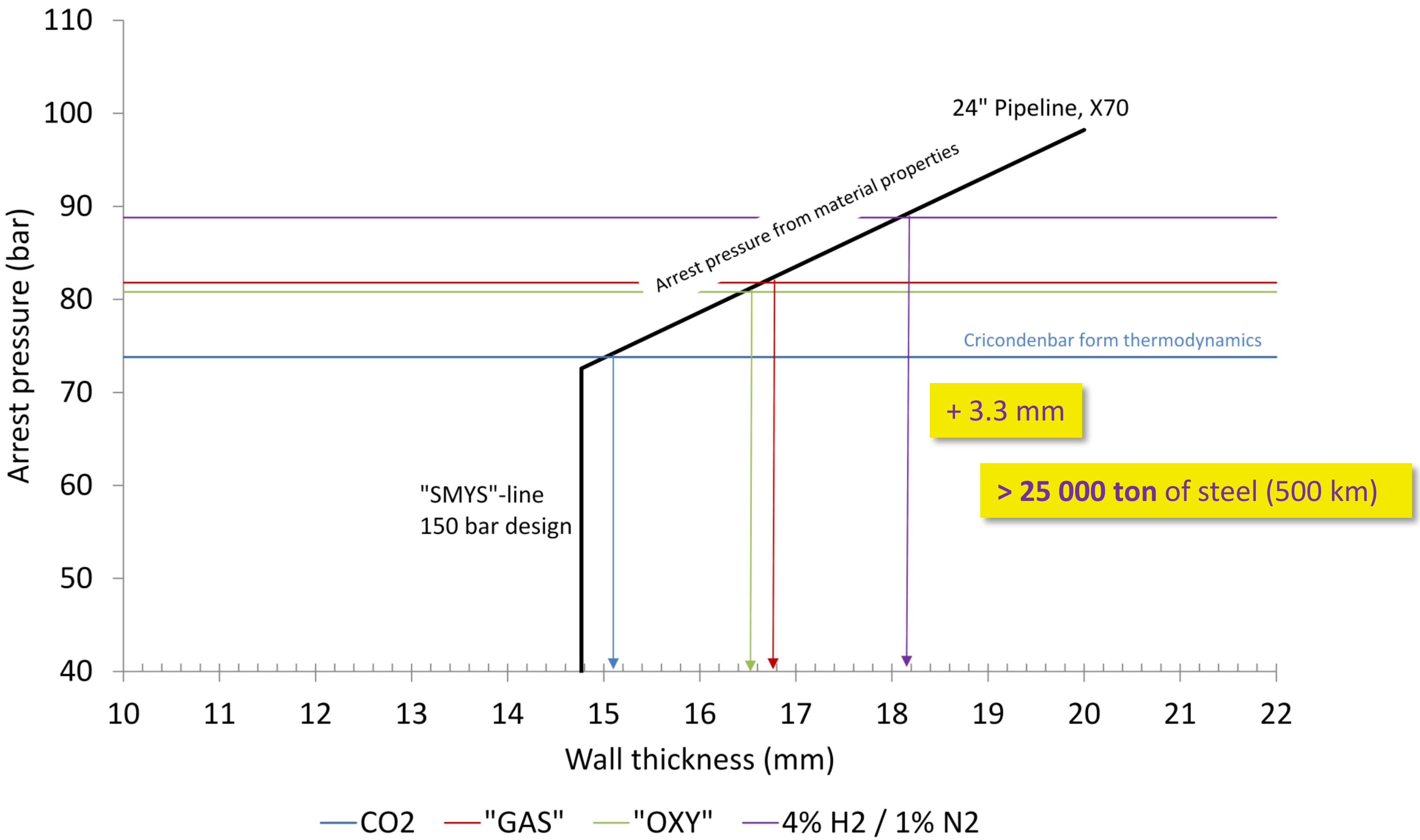

Pipeline sizes used in the analysis

Based on DNV-GL recommendations –
CLASS 3 pipeline: ($SMYS_{0.45}$+ 1.0 mm) + 12.5%

Size	Outside diameter	Wall thickness	Inside diameter
	(mm)	(mm)	(mm)
28"	711.2	30.2	681.0
24"	609.6	28.6	581.0
20"	508.0	23.8	484.2
18"	457.2	22.2	435.0

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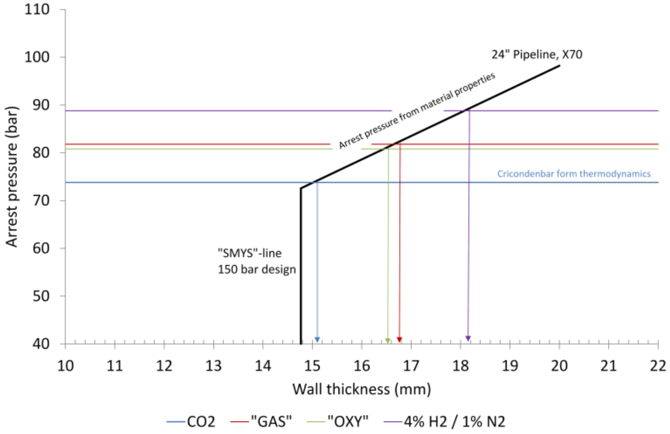

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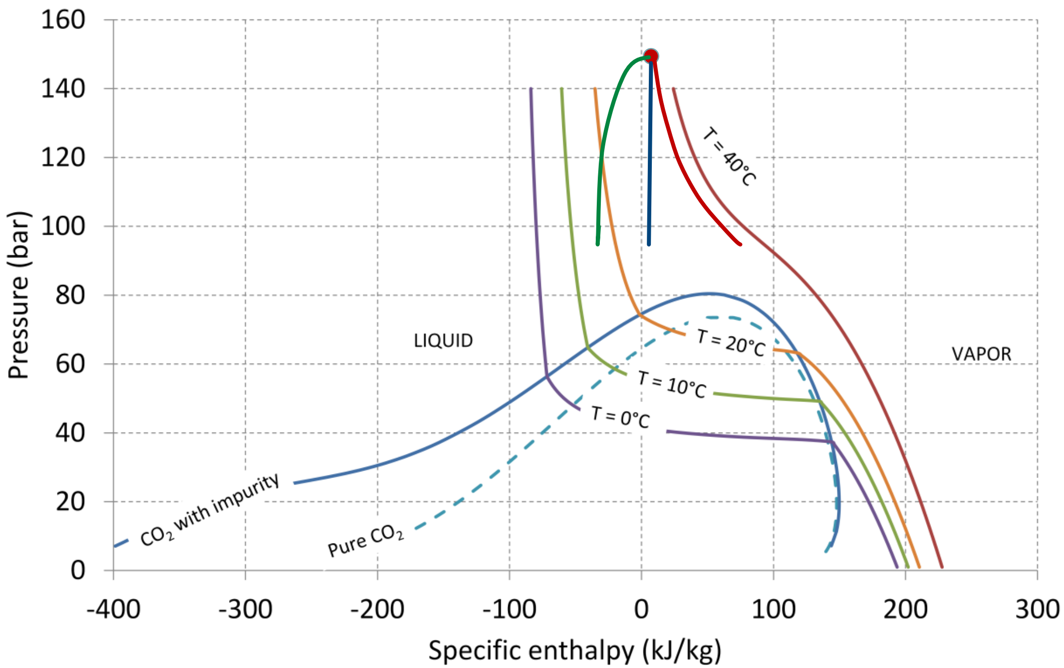
Possible path for pipeline pressure loss – principle

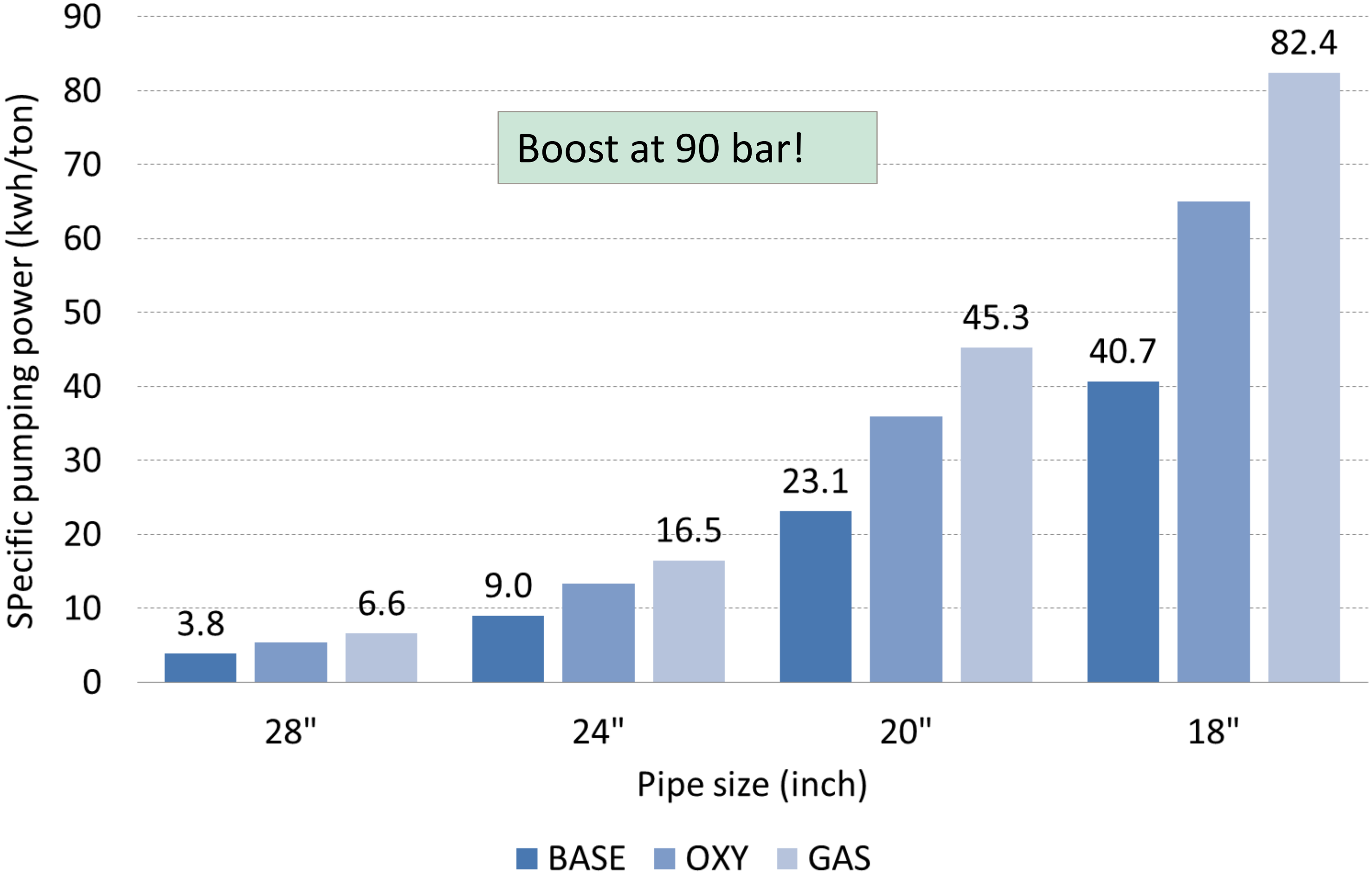


$CO_2/N_2/O_2$ - 4% impurity

Pressure loss from 150 to 90 bar

- Isothermal
- Adiabatic
- With ambient heat exchange

Power consumption 500 km for on-shore pipeline transport



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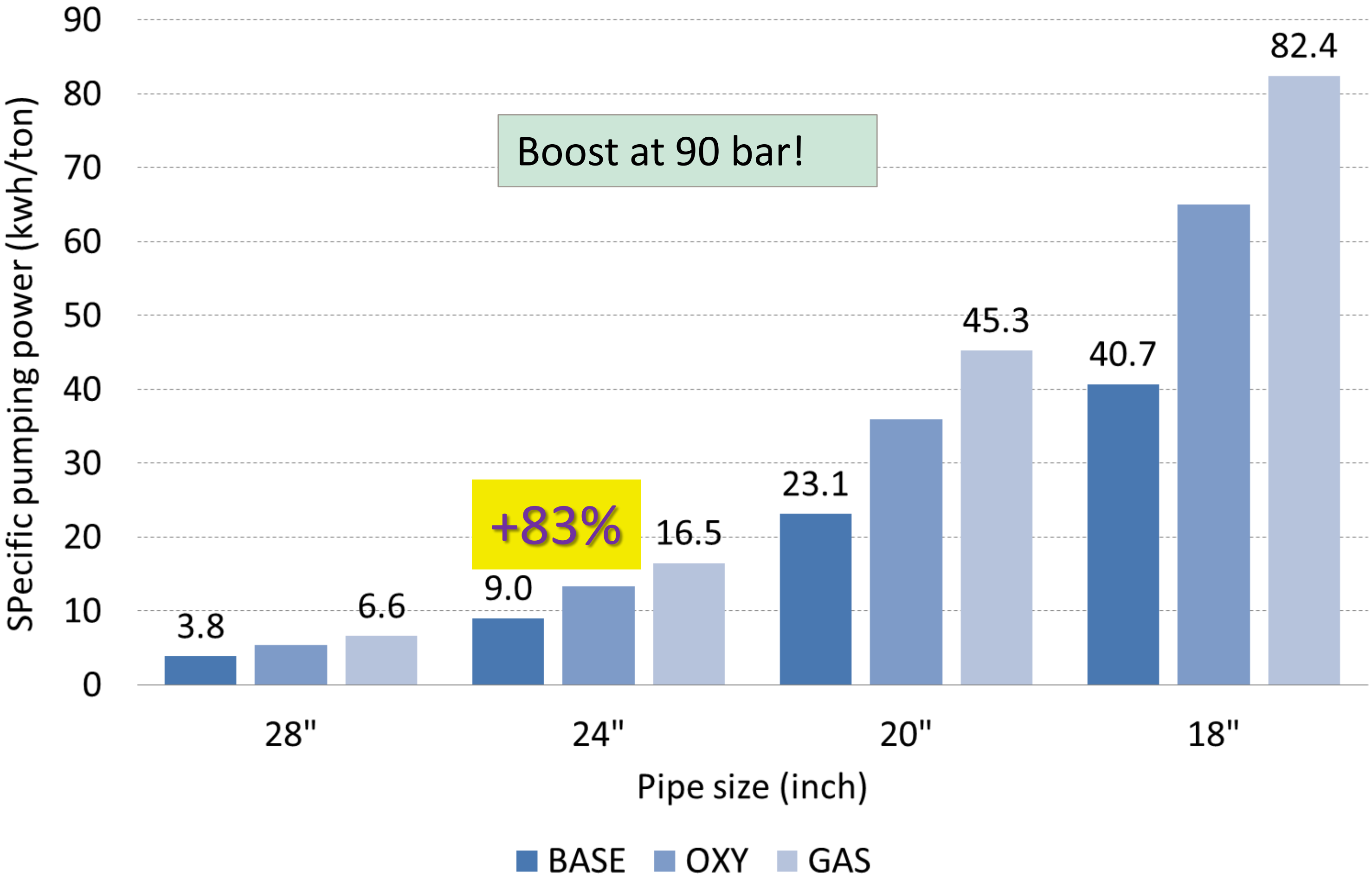
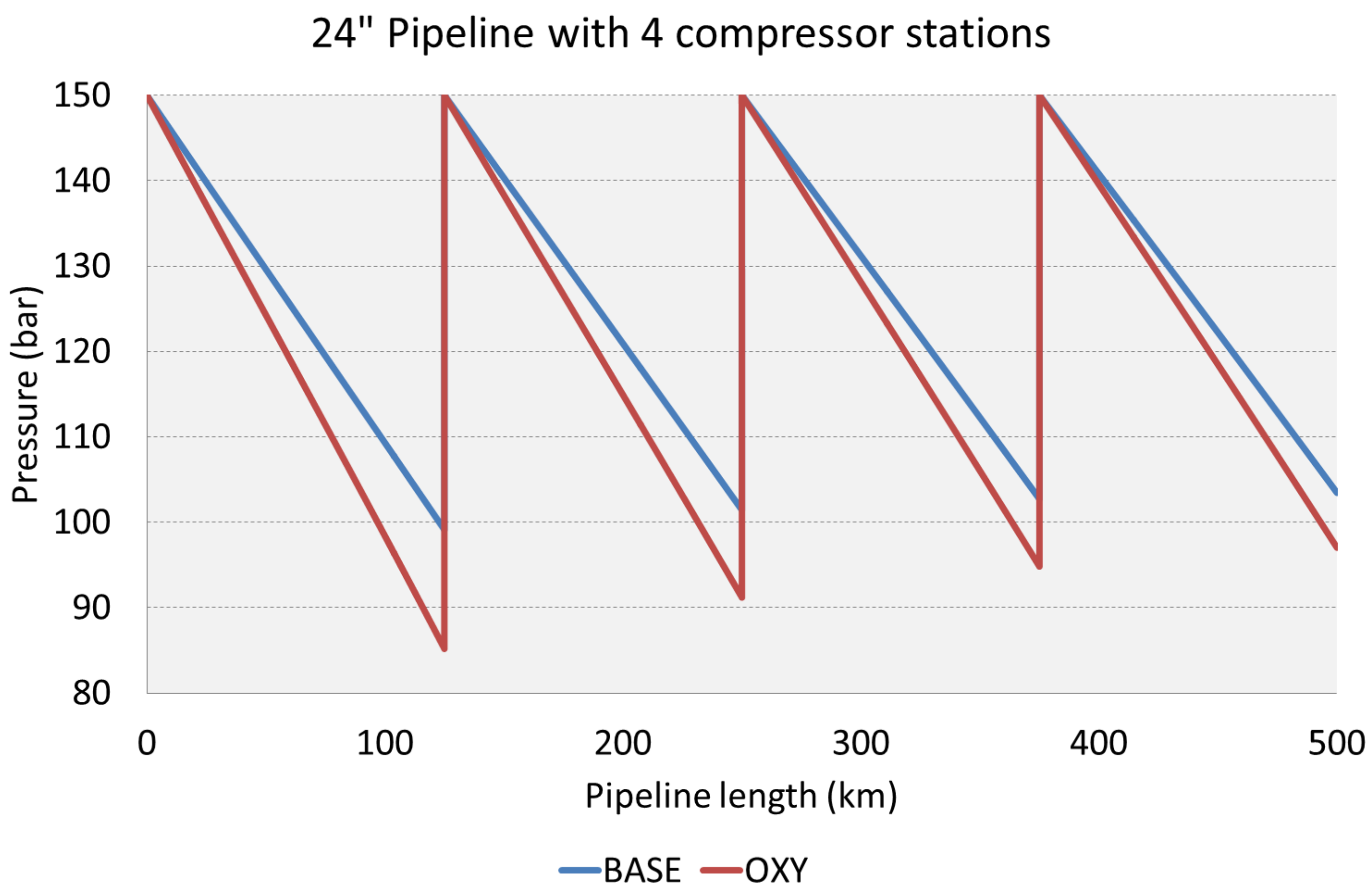
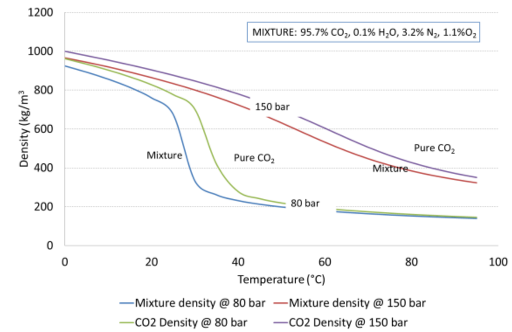
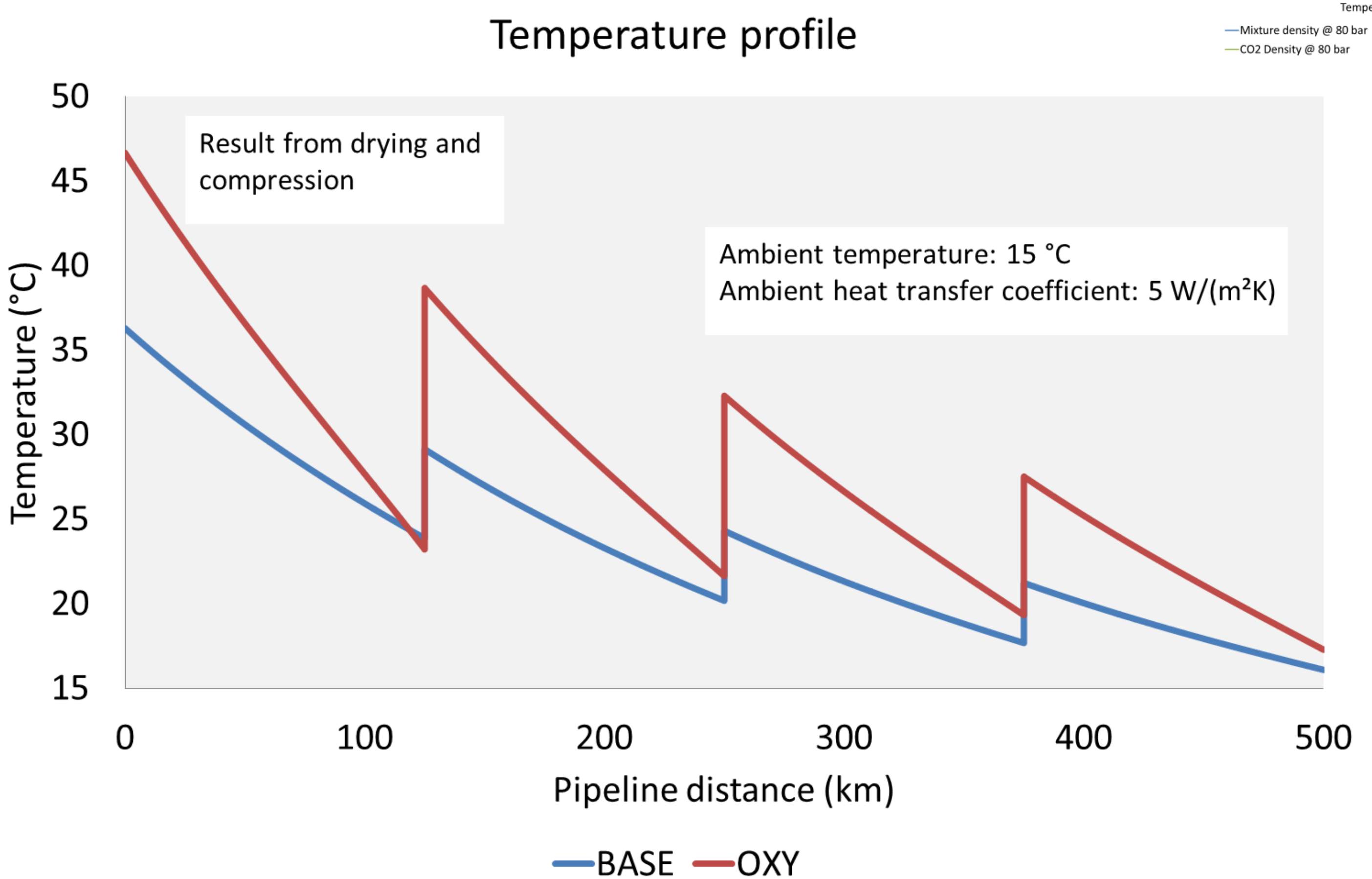


Pressure profile for pipeline transport

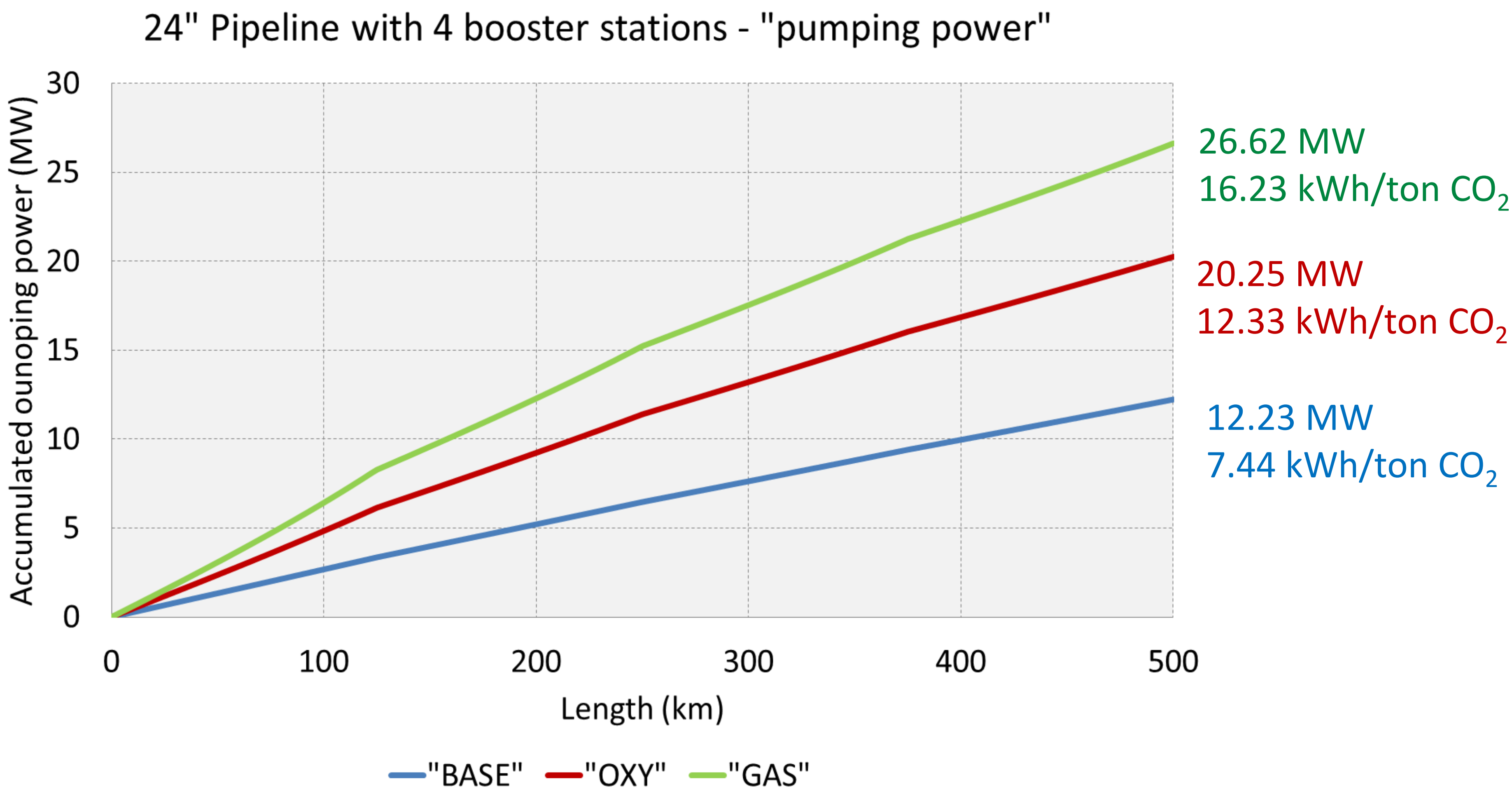


Temperature profile along a 24’’ pipeline

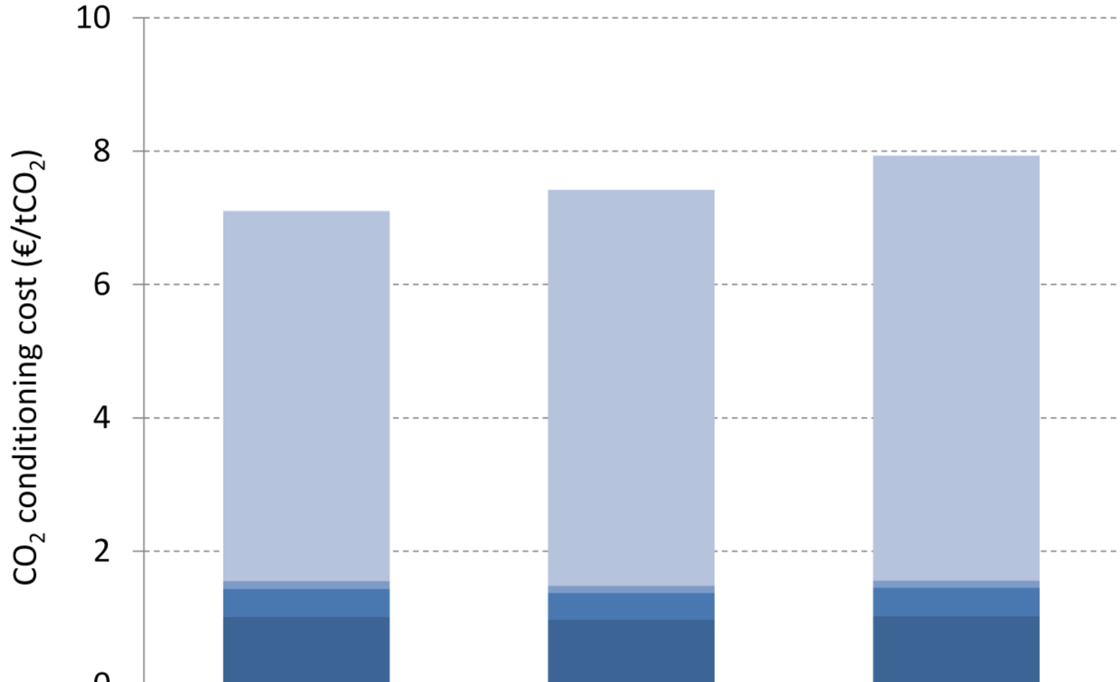




Required pumping power for pipeline transport

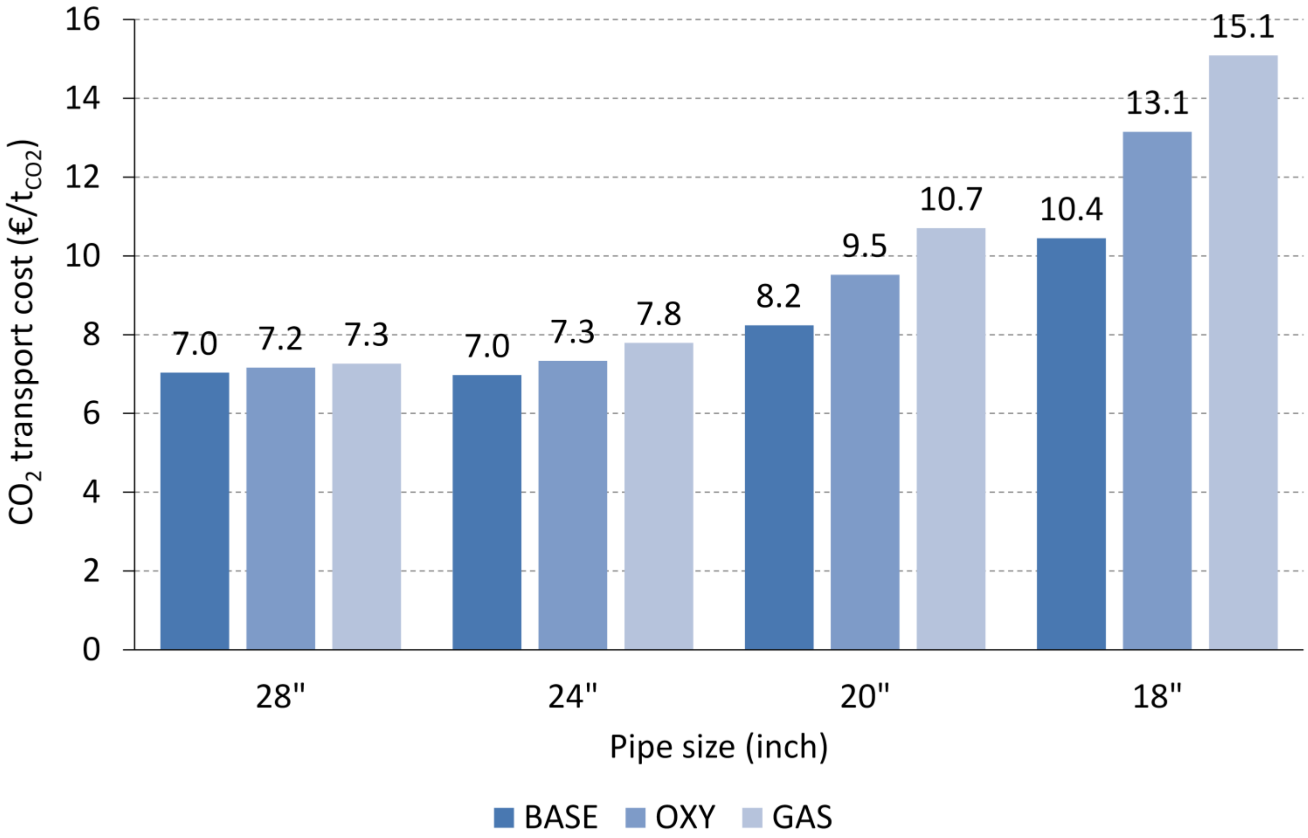


CO_2 conditioning cost of the BASE, OXY and GAS cases, €/tCO_2

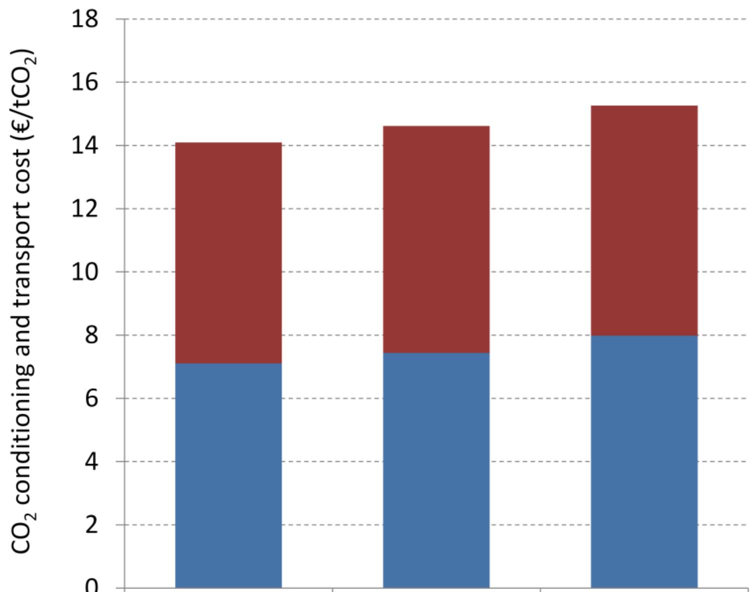


	Base	Oxy	Gas
Electicity cost	5.6	5.9	6.4
Cooling water consumption	0.1	0.1	0.1
Fixed OPEX	0.4	0.4	0.4
CAPEX	1	1	1

CO_2 transport cost of the BASE, OXY and GAS cases, €/tCO_2

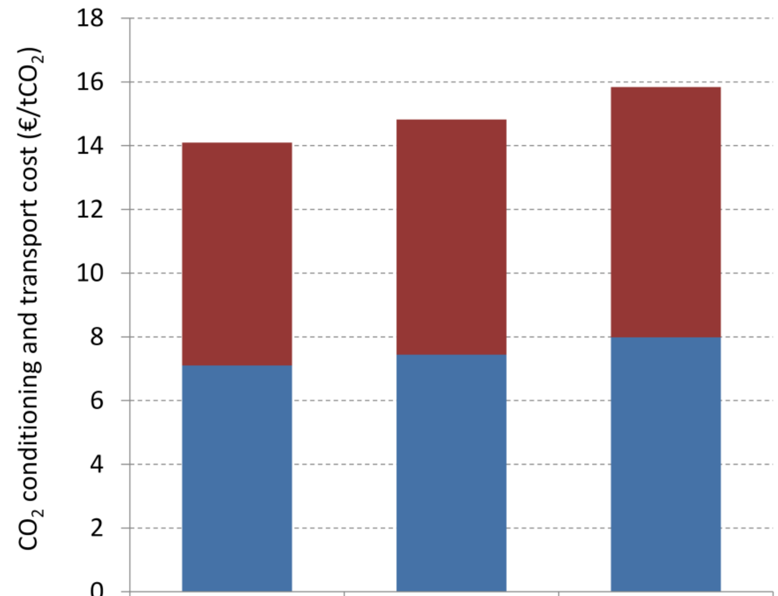


CO_2 conditioning and transport cost



	BASE	OXY	GAS
Transport	7.0	7.2	7.3
Conditioniong	7.1	7.4	8.0

Optimum pipeline diameter



	BASE	OXY	GAS
Transport	7.0	7.4	7.9
Conditioniong	7.1	7.4	8.0

24" pipeline diameter

Summary and conclusions

- Pipeline transport of CO_2 over 500 km
  - The results show that with 4% impurities from N_2 and O_2, the transport power consumption in a 24'' pipeline configuration can increase by 100%
  - to boundary conditions and need to be optimized on a case to case basis
  - The most important thermodynamic property is the density.

- Pipe design
  - It was shown how the cricondenbar for the transported fluid, combined with the possible operational envelope for the transport and the material properties for the pipeline should be used when evaluating the potential for RDF

- Economics:
  - The results showed a cost increase of 8.5% annually for conditioning and transporting CO_2 with impurities in a pipeline optimized for pure CO_2

Thank you for your attention!

Acknowledgement: The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7-ENERGY-20121-1-2STAGE) under grant agreement n° 308809 (The IMPACTS project). The authors acknowledge the project partners and the following funding partners for their contributions: Statoil Petroleum AS, Lundin Norway AS, Gas Natural Fenosa, MAN Diesel & Turbo SE and Vattenfall AB.

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